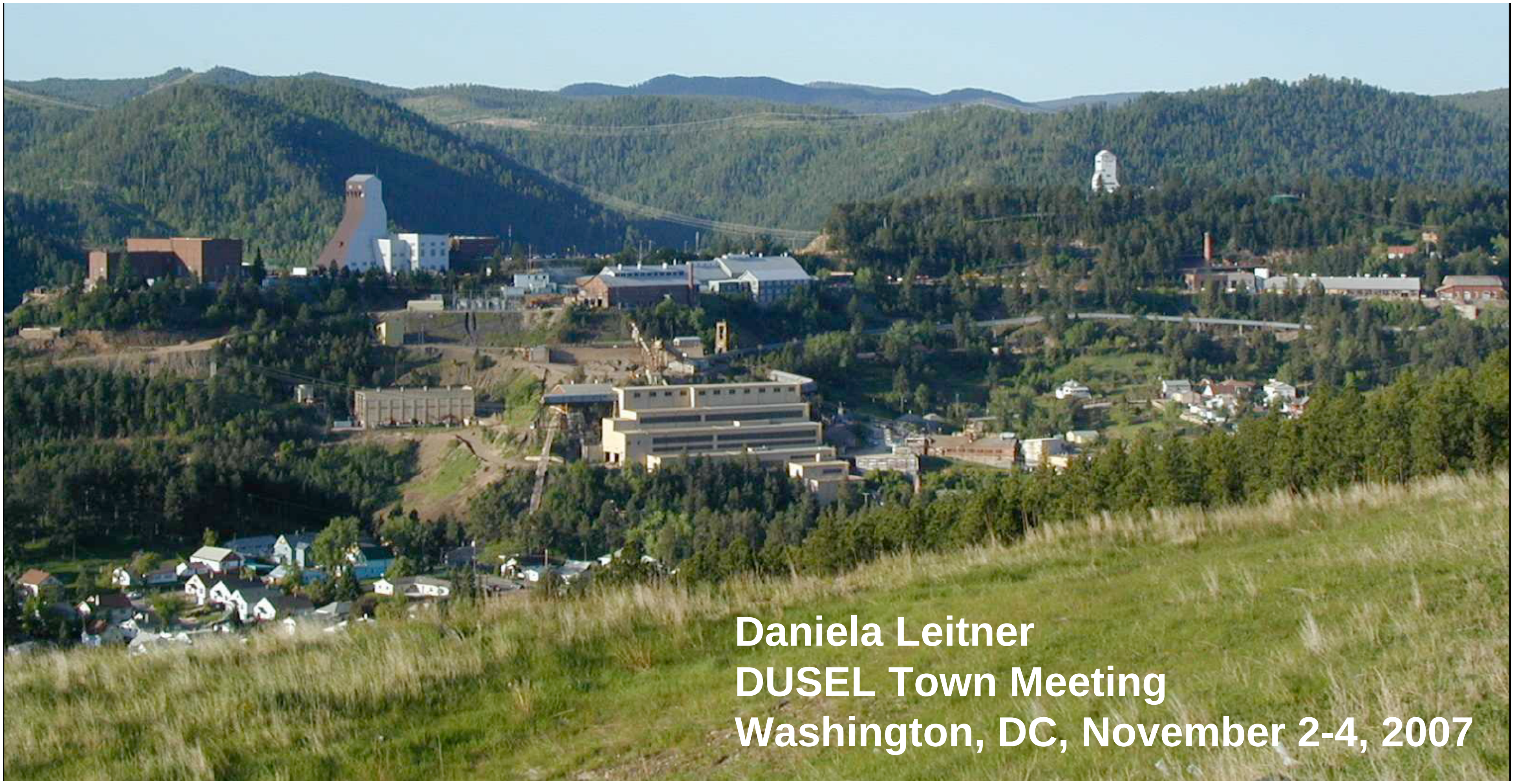
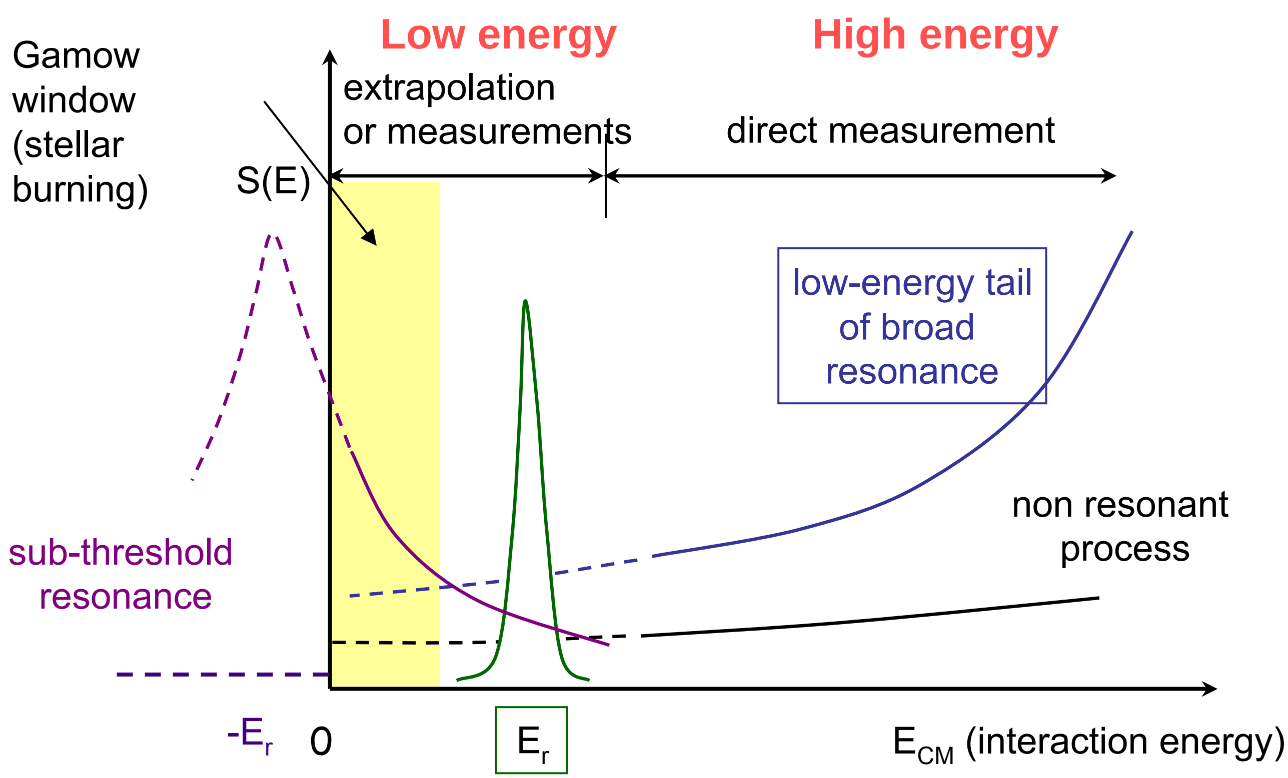
Accelerator Options and R&D for an Underground Accelerator Laboratory at DUSEL



S(E) Astrophysical S-Factor determines the reaction rate

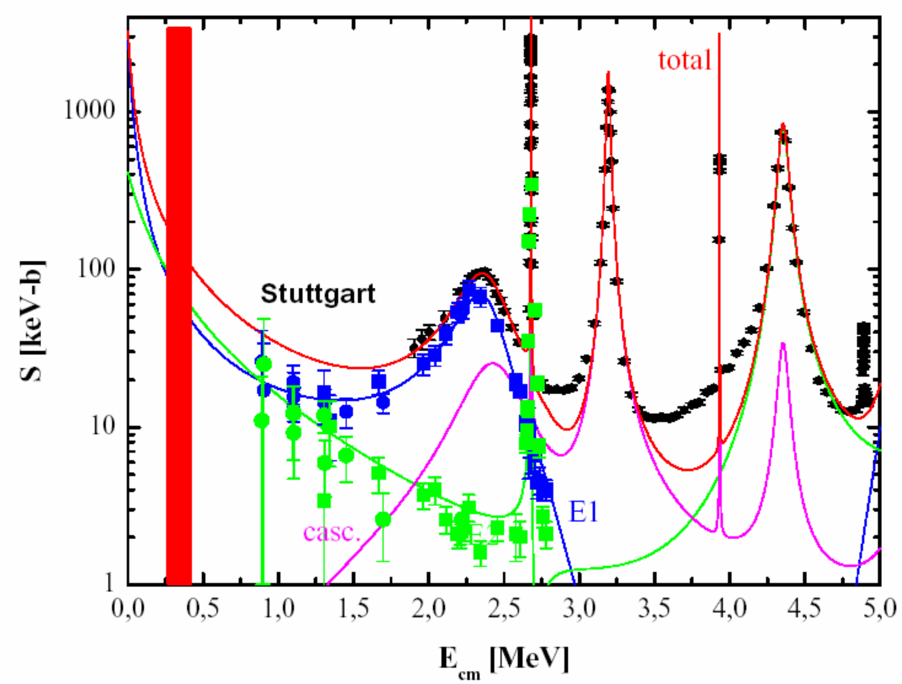
Several mechanisms contribute to the cross section and require different energy ranges	
Resonance well above Gamow window	some high energy measurements to connect to resonance, measure as low as possible
Resonance near Gamow window	must map out significant resonance structure
Sub-Threshold Resonances	measure as low as possible/ use other methods to determine resonance strength
Non-Resonant	measure as low as possible



$^{12}C(\alpha,\gamma)^{16}O$

The reaction that all nuclear astrophysicists want to know…

- Determines the amount of oxygen and carbon, “Life” element creation, timescales, dispersion
- Determines isotopic abundances in progenitors of Type 2 Supernovae
- Type Ia Supernova, central carbon burning of C/O white dwarf



- Unfortunately has a very difficult complex resonance structure, interfering broad resonances causes difficulties in the reliability of low energy extrapolation.
- Needs to be measured over a wider energy range
- Target impurities cause beam induced background

Lucio Gialanella, INFN, Workshop Nov. 2006, Perugia, Italy

ALNA - Accelerator Laboratory for Nuclear Astrophysics Underground

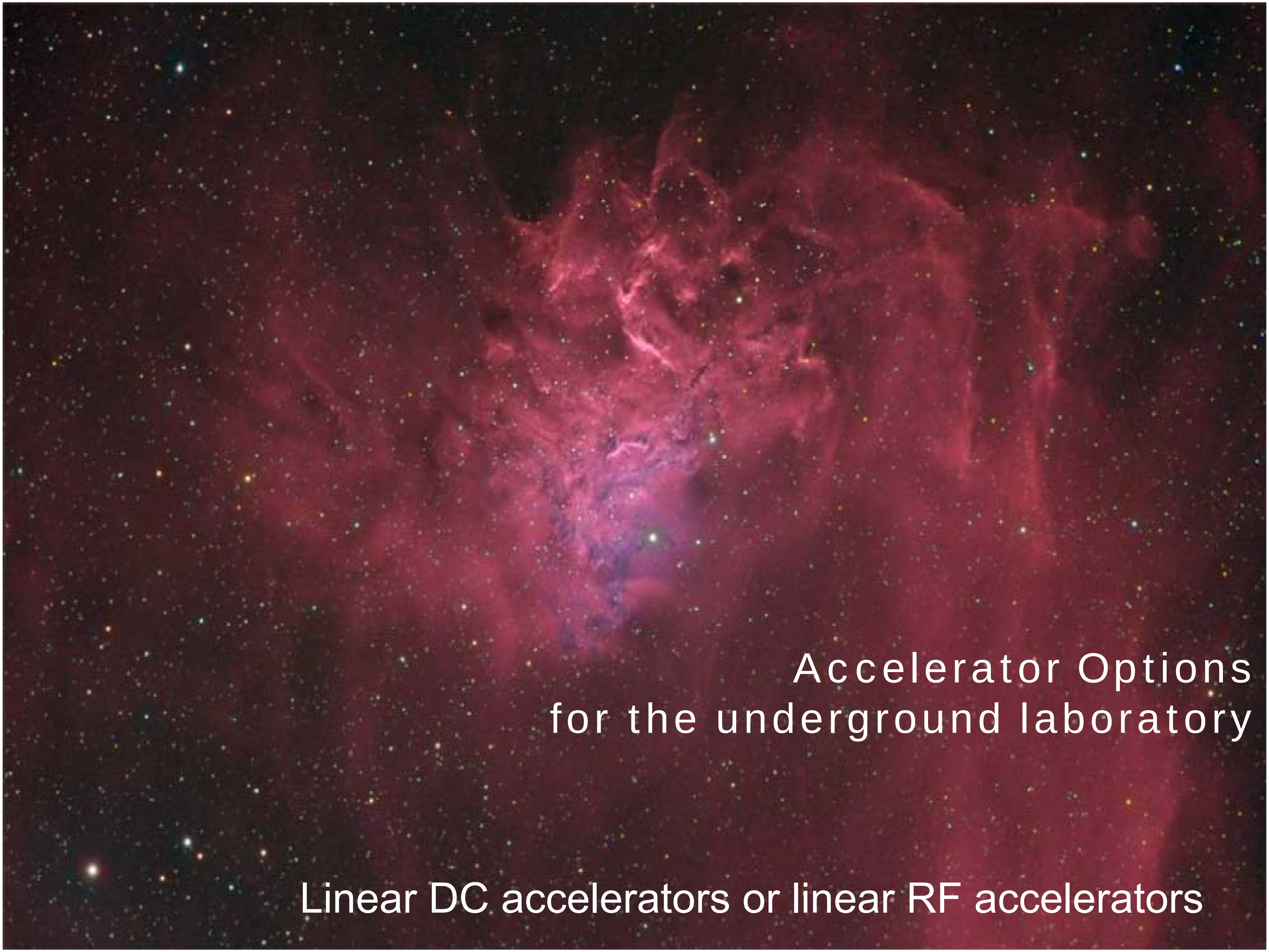
(http://www.deepscience.org/TechnicalDocuments/Final/ualna_final.pdf)

Two accelerator based experimental areas

- A compact, high intensity low energy accelerator for forward kinematics reactions (complementary or expanding on LUNA activities, need priority list of experiments)
  - CLAIRE
  - High current DC accelerator
- A high intensity heavy ion accelerator for inverse kinematic reaction and low energy fusion reactions (need to develop a priority list of reactions that benefit from going underground)
  - RFQ LINAC
  - Pelletron, Tandem
  - Dynamitron, Singletron

•The energy range of both accelerators combined should ideally cover beam energies from as low as 50keV up to 1 MeV/u for ion masses up to Mg

•The two accelerators should have an overlap in energy range for comparison between experiments over a common energy.



Accelerator Options
for the underground laboratory

Linear DC accelerators or linear RF accelerators

Linear DC accelerators, classic approach for astrophysics studies

- DC accelerators
  - Air or SF_6 Tanks
  - Core is HV terminal + insulating column for acceleration

Notre Dame Tandem,
Terminal voltage 10 MeV
But negative ions required for external injection (low currents)

6 MV HVE Singletron

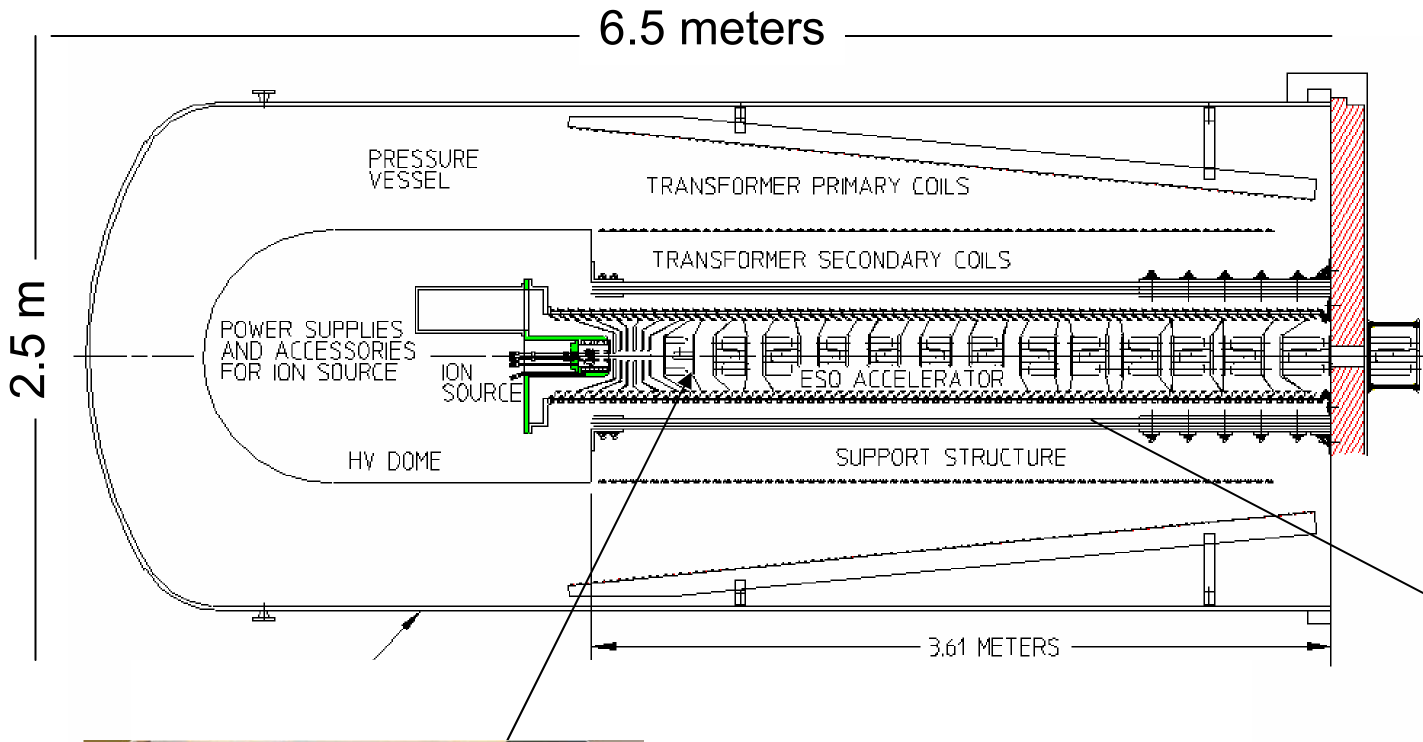
5.5 MeV Van De Graaf Injector
Hahn-Meitner Institute, Berlin
(ECR ion source at the terminal)

Power Supply Types for DC Accelerators

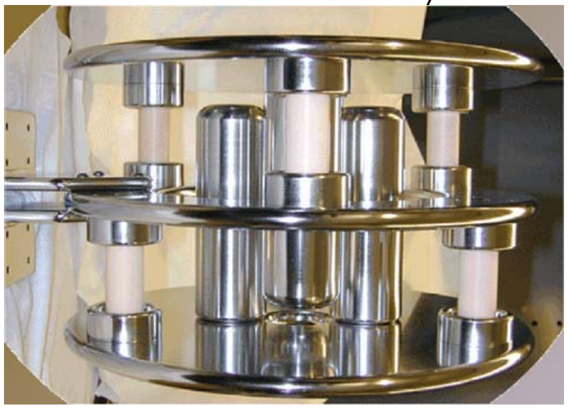
- Van de Graaff (including pelletron) – low current but capable of reaching terminal potentials > 10 MV
- Cockcroft-Walton – uses a ladder network to build voltage up to ~1 MV
- Dynamitron – a "shunt-fed" type Cockcroft-Walton that has higher current capability and provides voltages to a few MV at higher current (a few mA)
- External transformer – high current capability but high voltage limited by breakdown between windings
- Coaxial transformer – a high current (>10 mA) and high voltage design (LBNL, 2.5 MV accelerator R&D)

High current accelerator development is conducted at LBNL

Designed for BNCT application 50mA protons at 2.5MeV



Primary Winding
of the air- coupled
coaxial Transformer

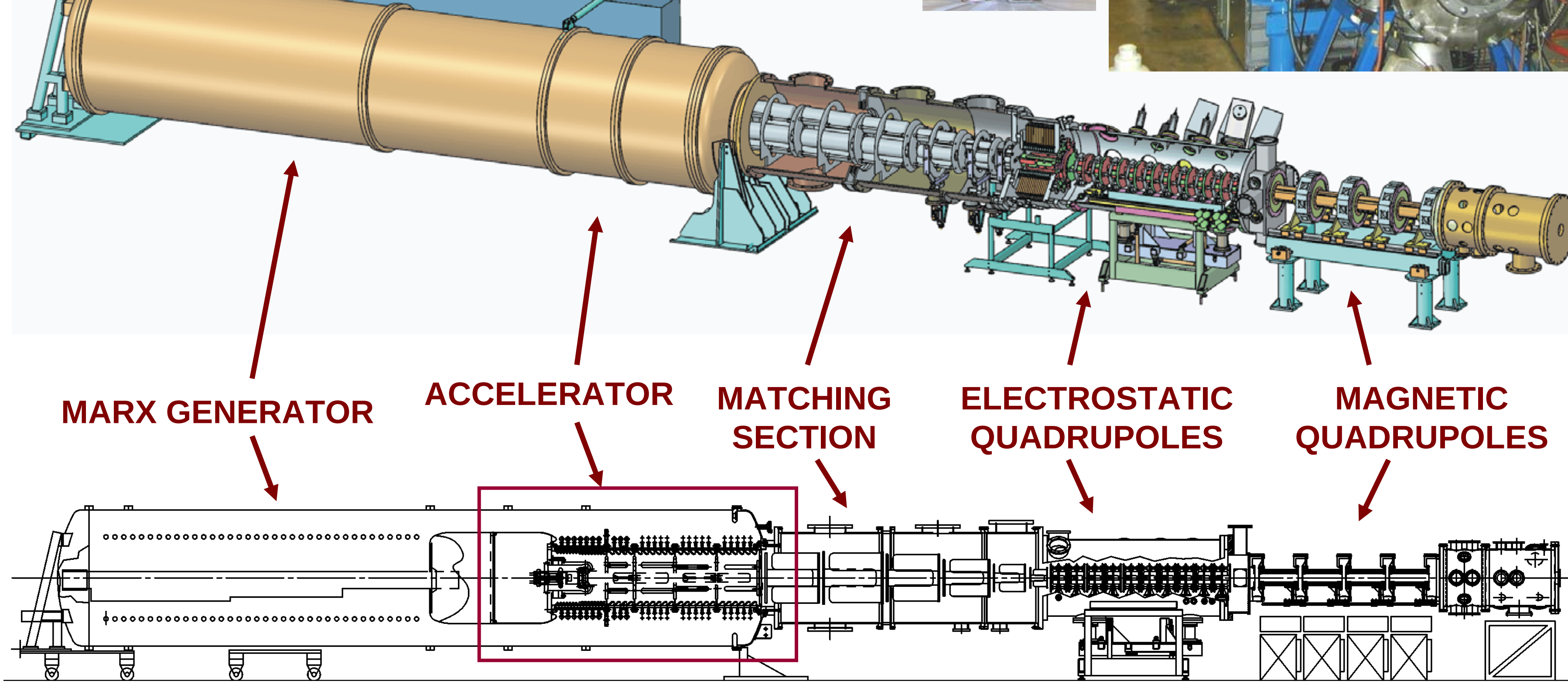


- **E**lectro**S**tatic **Q**uadrupole (ESQ) accelerator provide strong focusing for high currents and allow for energy variability as well as current variability
- Suppress secondary electrons to minimize electrical breakdowns

J. Kwan et al. LBNL

High current accelerator development is conducted at LBNL
High Current Experiment (HCX), LBNL Heavy Ion Fusion Program

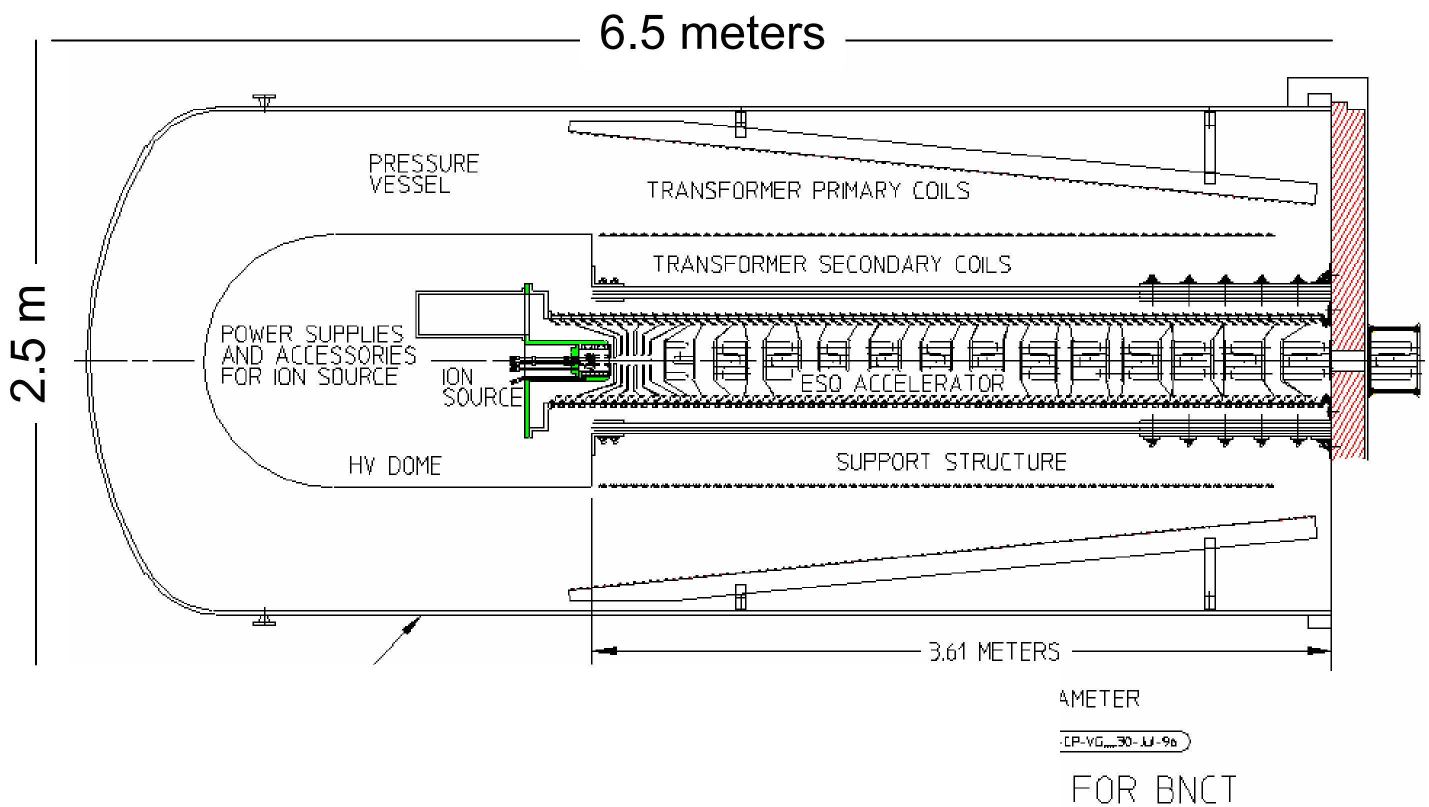
up to 1.7 MeV, ~700 mA, τ ~ 3-10 μs
every 1- 10 minutes, Marx Generator



M. Leitner –May 2005

P A Seidl, et al., " The High Current Transport Experiment for Heavy Ion Inertial Fusion",
LBNL-53014, (2003).

Needs R&D effort to develop as possible underground accelerator



- **High current singly charged ions**
- **For higher energies replace ion source with compact ECR**
- **Mass analyzing and matching section after the acceleration columns**
- **Should be mounted vertically**
- **Challenge: maintaining adequate focusing over the wide range of energies and intensities**

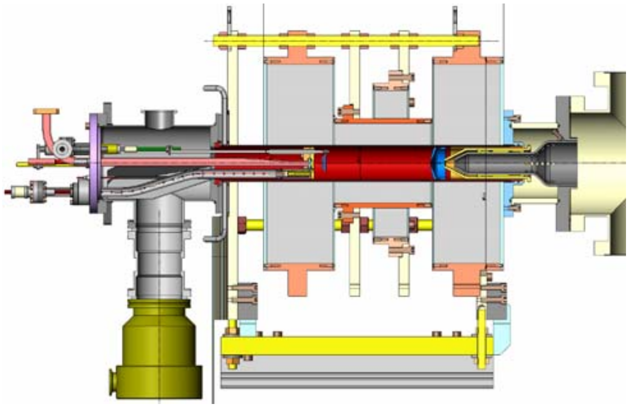
DC Accelerator Advantages and Disadvantages

- **Limited space, power and weight capacity at the terminal**
- **Energy is limited by the terminal voltage**
- **Limited ion beam flexibility**
- **Intensity limitations**

- **Very good energy stability 0.002% per hour**
- **Energy resolution: 0.02%**
- **Good energy variability**

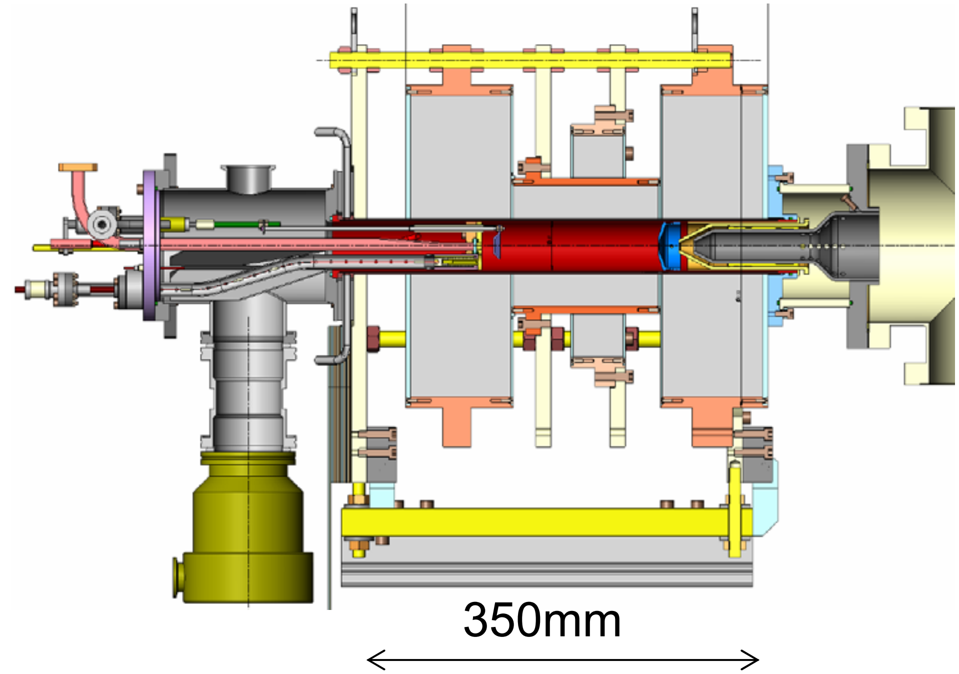
R&D needs if this approach is chosen

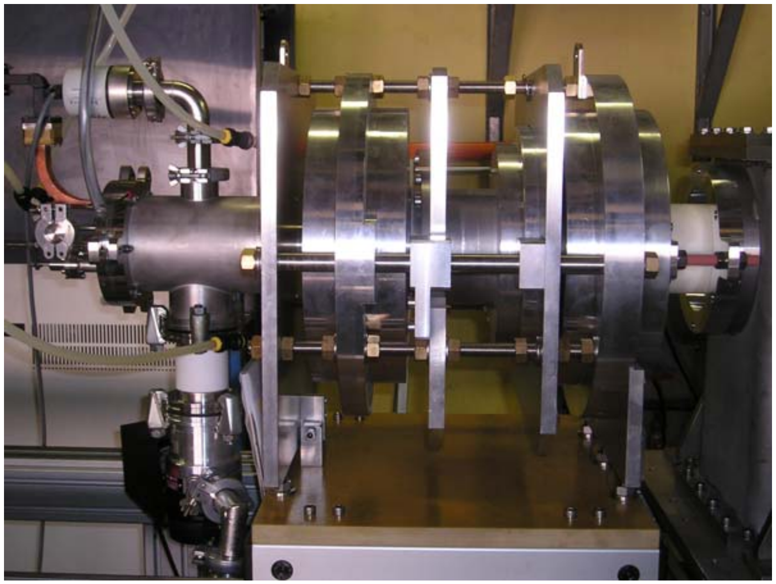
- **ESQ DC accelerator**
  - intensity and energy variability
  - high power HV power supply
- **Compact ECR ion sources for medium charge states up to Mg or Al**



Oak Ridge ECRIS, CEA-Grenoble, Denis Hitz

- Compact ECR ion source that delivers medium high charge state
- Size matters! Must optimize maximum weight and power available
- Beam analyses must been conducted after acceleration
- Accelerator optics must be flexible enough (low current to high currents)
- DC HV power supply must support a few mA drain current





Oak Ridge High Voltage Platform

Oak Ridge ECRIS, CEA-Grenoble, Denis Hitz

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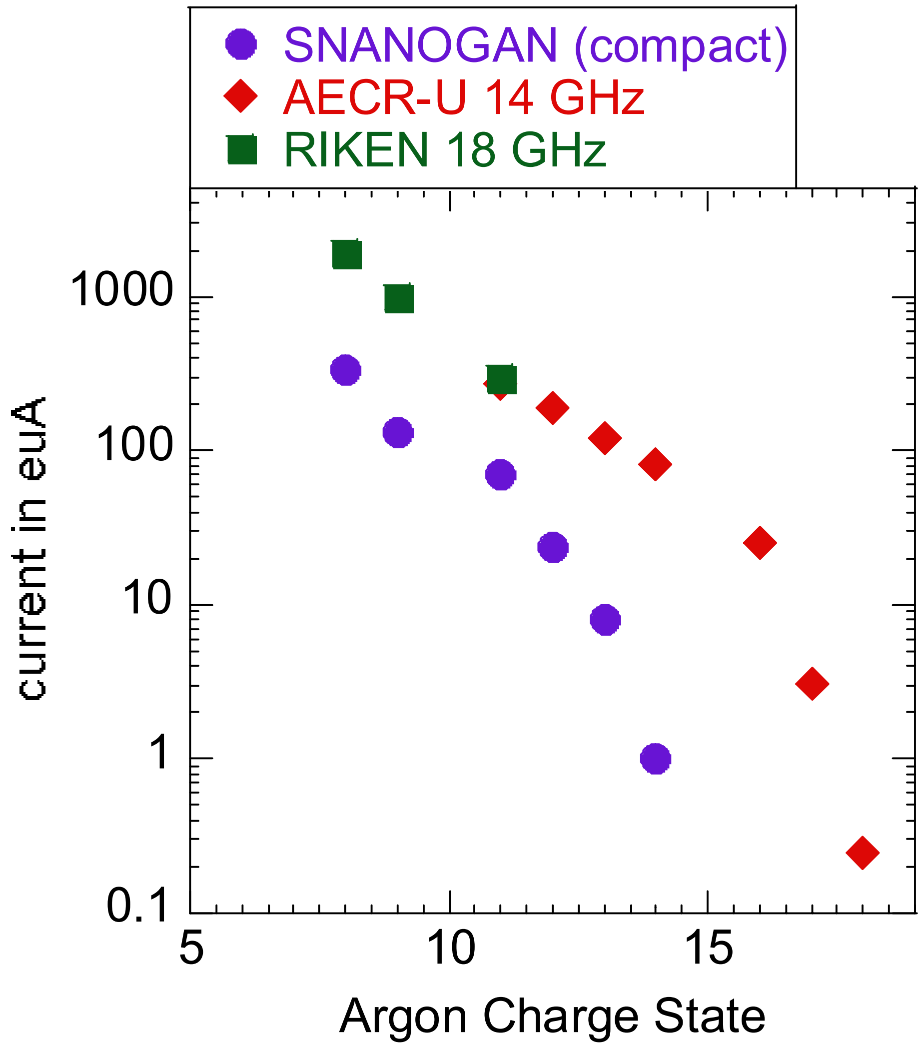

Oak Ridge ECRIS, CEA-Grenoble, Denis Hitz

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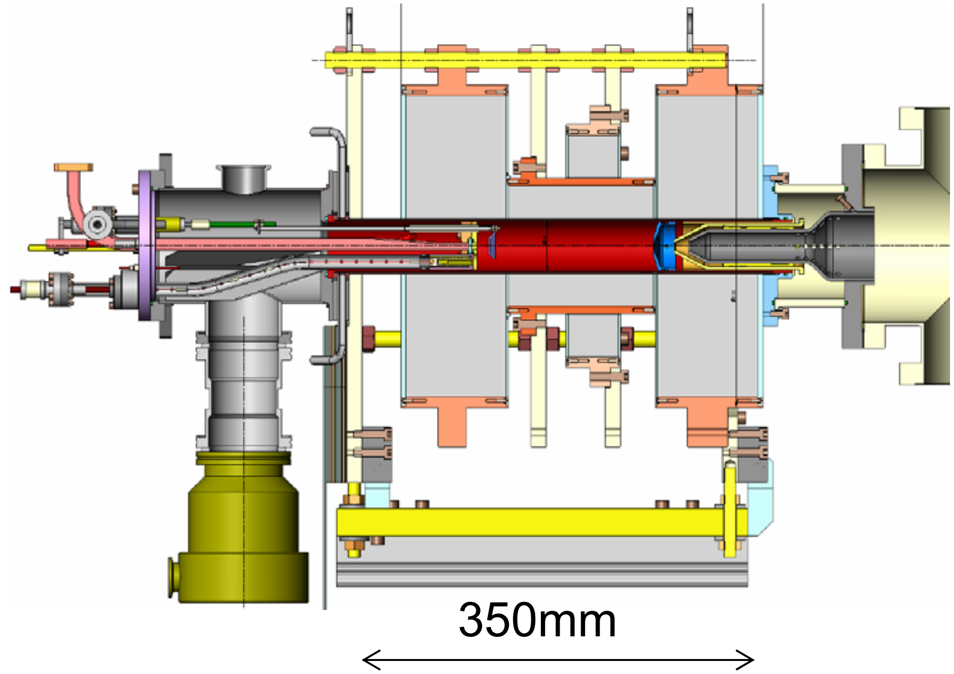
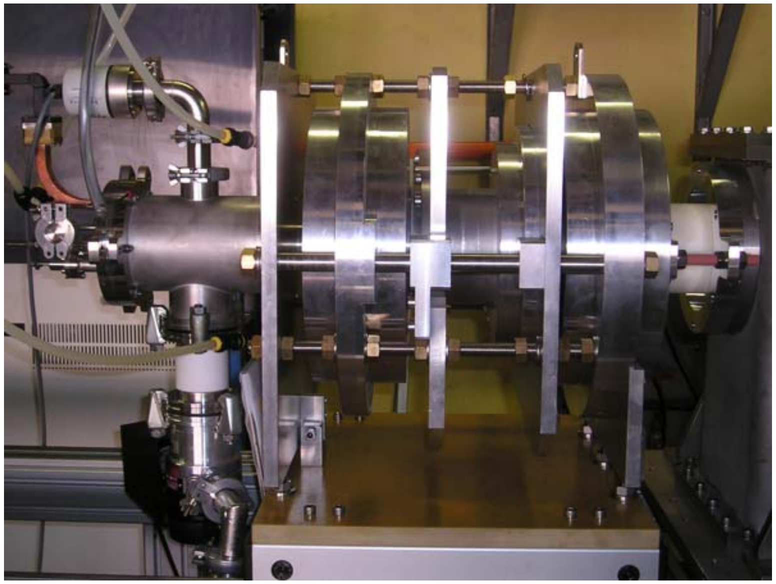


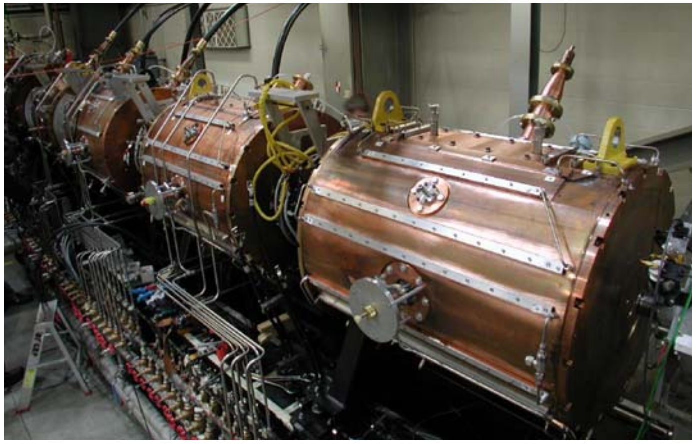


Oak Ridge High Voltage Platform

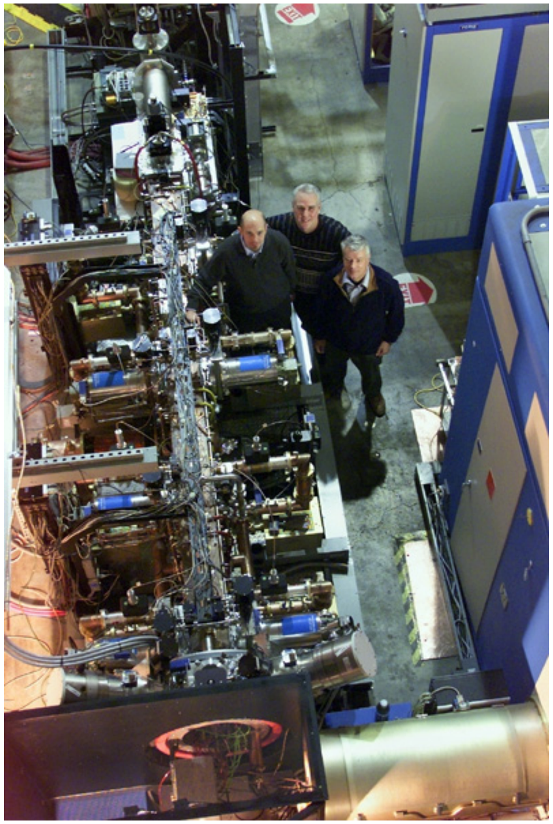
LINAC accelerator for astrophysics

1. RFQ post-acceleration + Single Cavities
2. Design parameter: Input M/Q
3. >10 mA (singly charged ions)
4. <1mA (medium charged ions)
5. Energy resolution/Intensity trade off

determines RF frequency, size, cost



ISAC Drift Tube LINAC DTL
Canada, R. Laxdal



SNS H^- RFQ, John Staples, LBNL

LINAC accelerator

- **Energy stability 0.07%**
- **Energy resolution 0.2-1.0%**
- **Trade off between intensity and energy resolution**

- **Very flexible, any ion beam**
- **End energy is easily upgradeable (add another cavity)**
- **Timing capabilities for background reduction RFQ/LINAC are compact and efficient**
- **Good energy variability**

R&D needs if this approach is chosen

- **Flexible low energy injector**
- **Study to optimize the design parameters for this application (CS, intensities, SC…)**
- **Optimize buncher to minimize the energy spread**
- **High resolution beam line vs high intensity beam line ?**


Accelerator Options
for the underground laboratory
Low Energy Accelerator 50-400keV

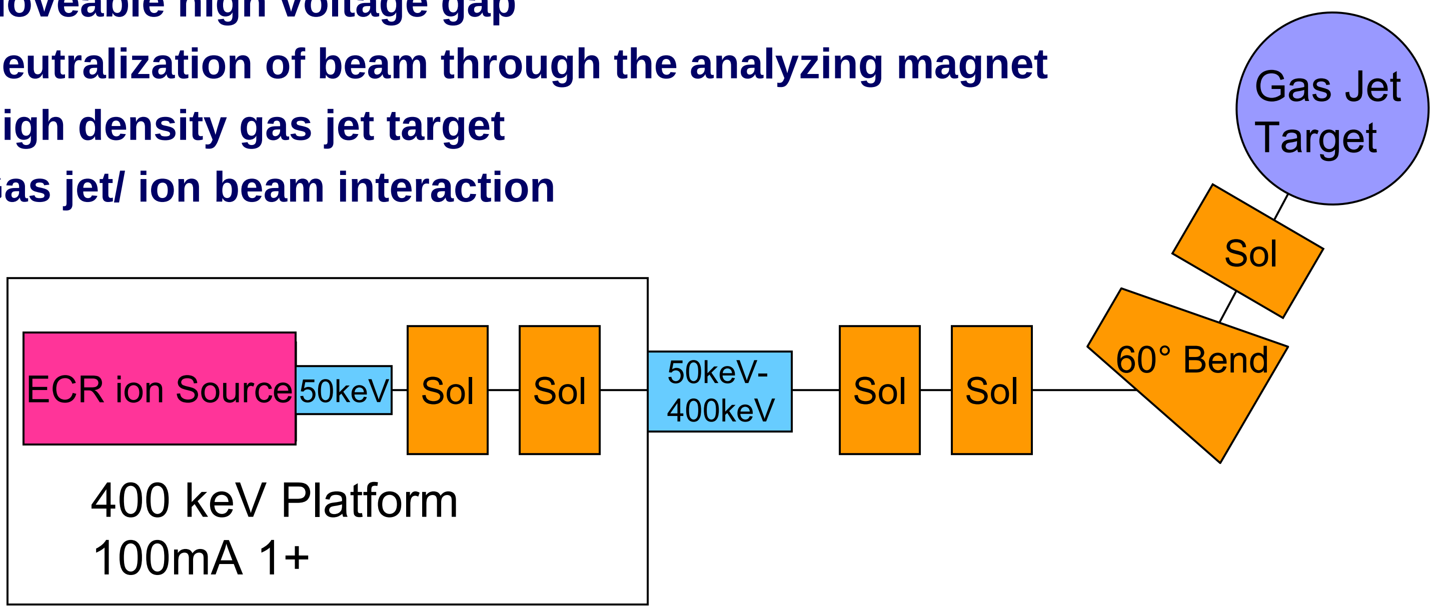
CLAIRE would be a powerful option as low energy accelerator

Stage 1: Singly charged ions using a high current microwave source, 50 to 400keV, up to 100mA

Stage 2: Add medium charge state ECR source for higher energies at several 100pμA, maximum energies 800keV He, 1.6 MeV C, 2 MeV N

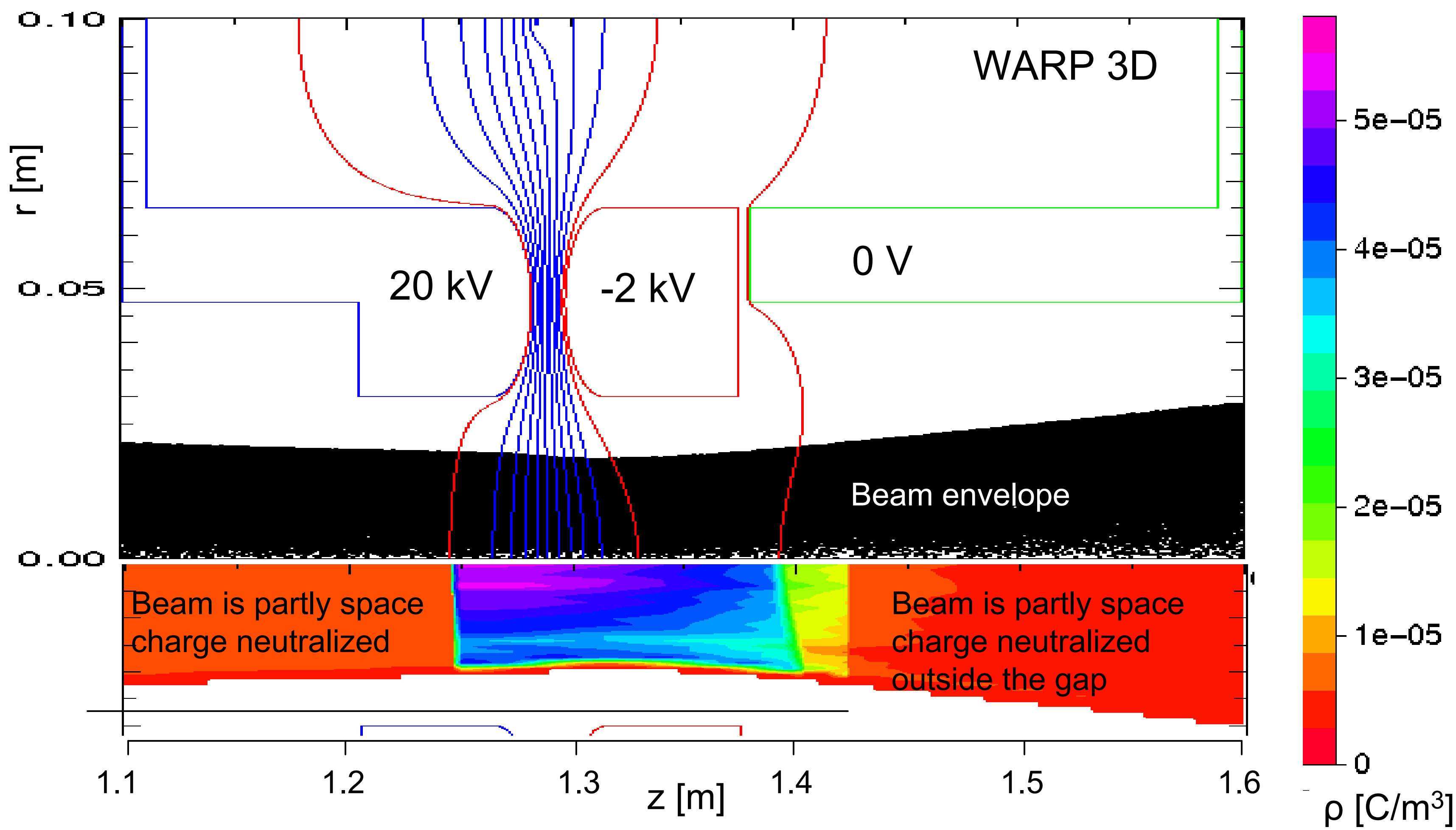
R&D items if this approach is chosen

- **Moveable high voltage gap**
- **Neutralization of beam through the analyzing magnet**
- **High density gas jet target**
- **Gas jet/ ion beam interaction**



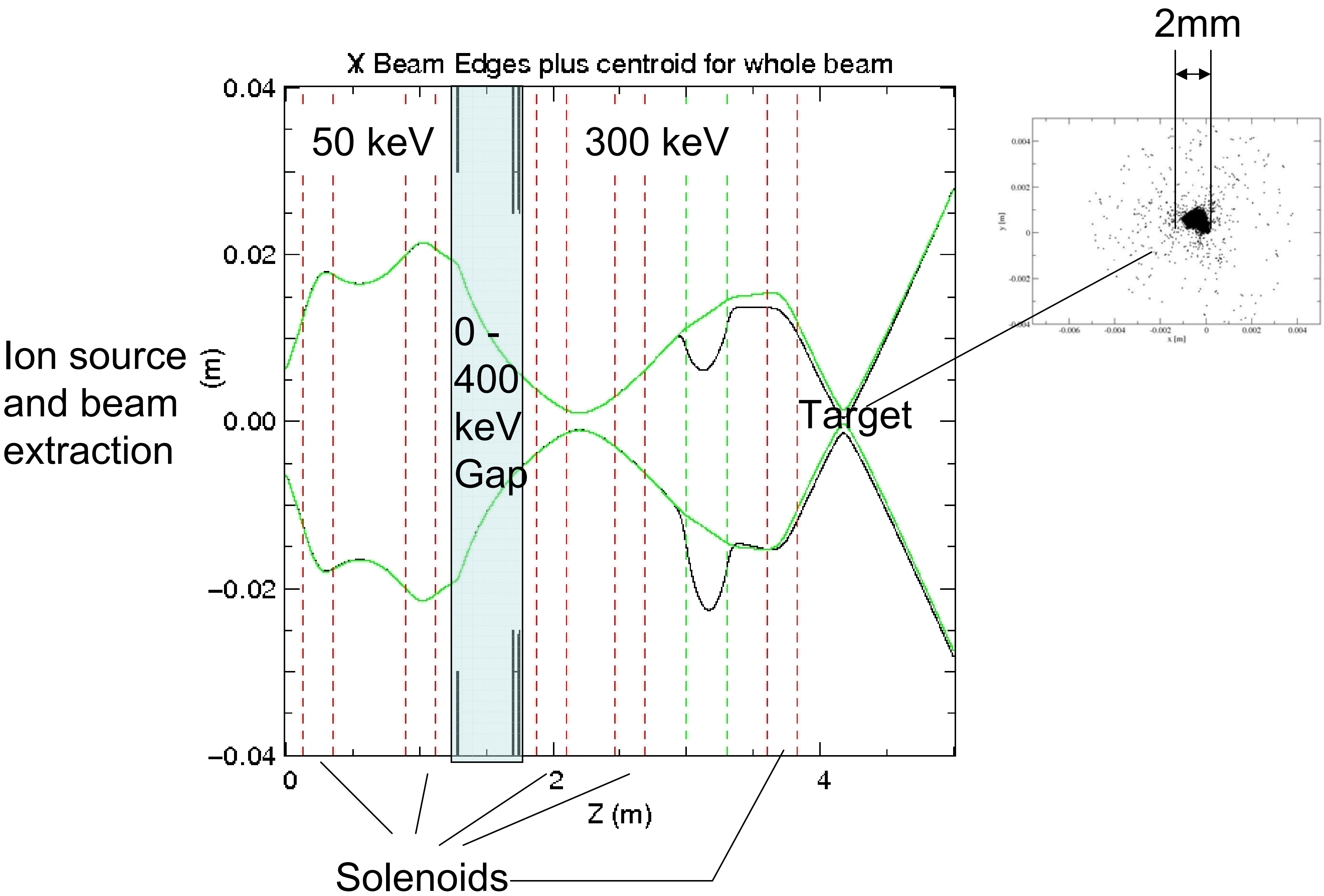
D. Leitner, D.Todd, P.Vetter, M.Leitner, J. Benetiz

Movable high voltage gap to minimize emittance growth in the acceleration column and ensure maintaining the beam properties over the energy range

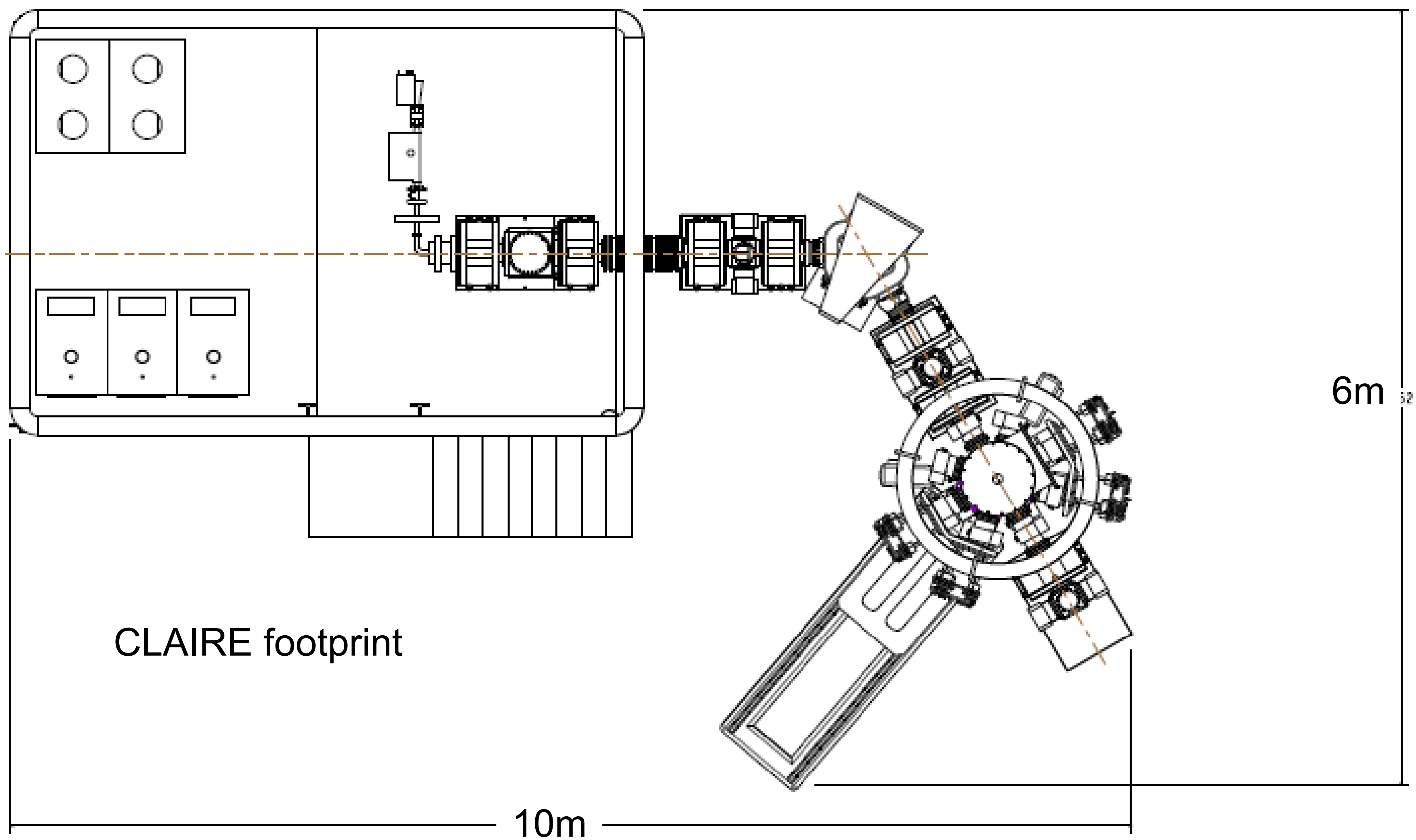


- Electron shielding of beam potential is not present in the gap region, significantly increasing beam emittance
- This region must be kept as small as possible at each acceleration voltage to minimize emittance growth

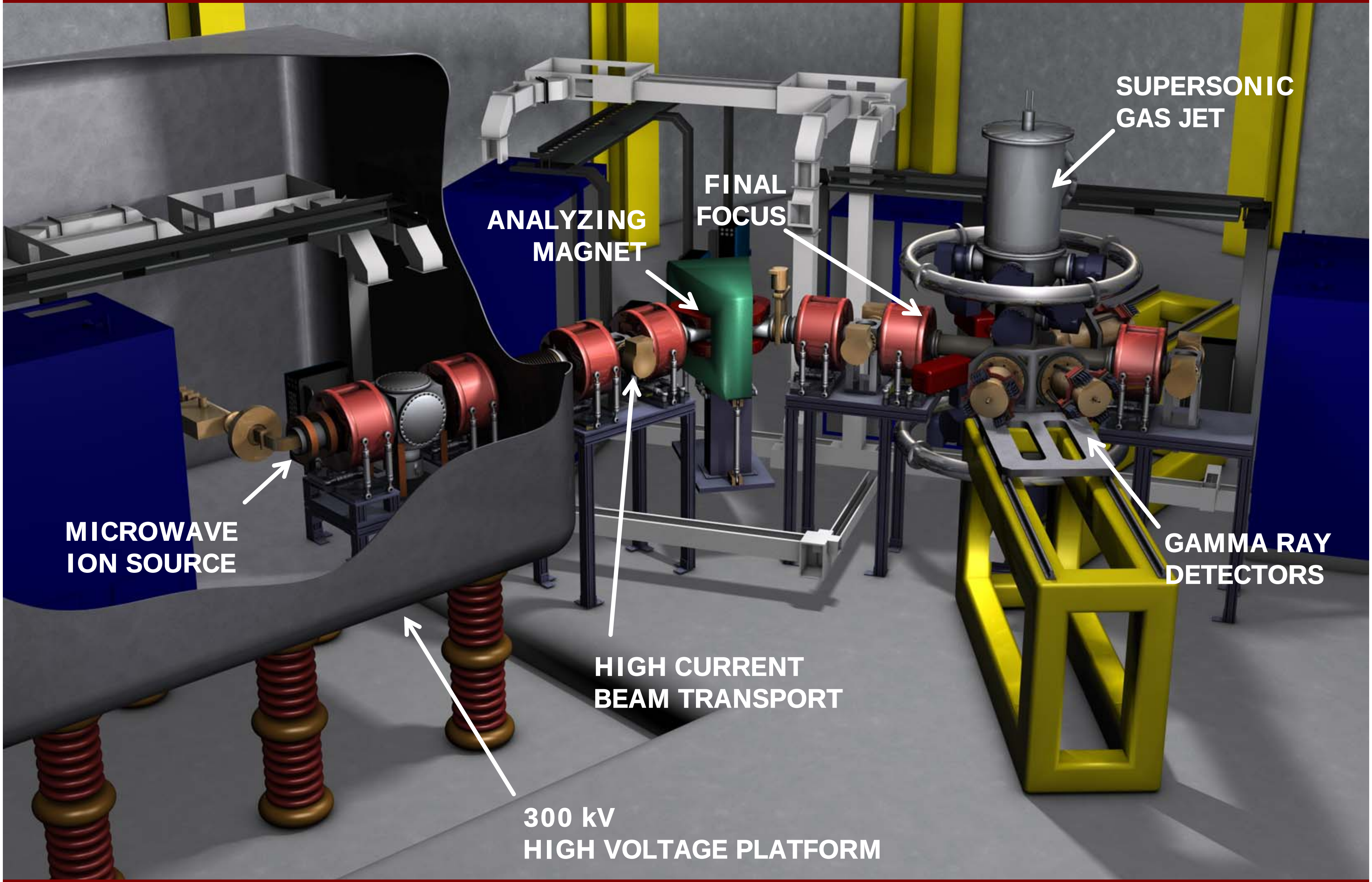
Beam envelope for 300 keV WARP Code



- Cost estimate cost estimate to DOE for long-range planning of capital equipment funding submitted
- Preliminary accelerator R&D has been conducted

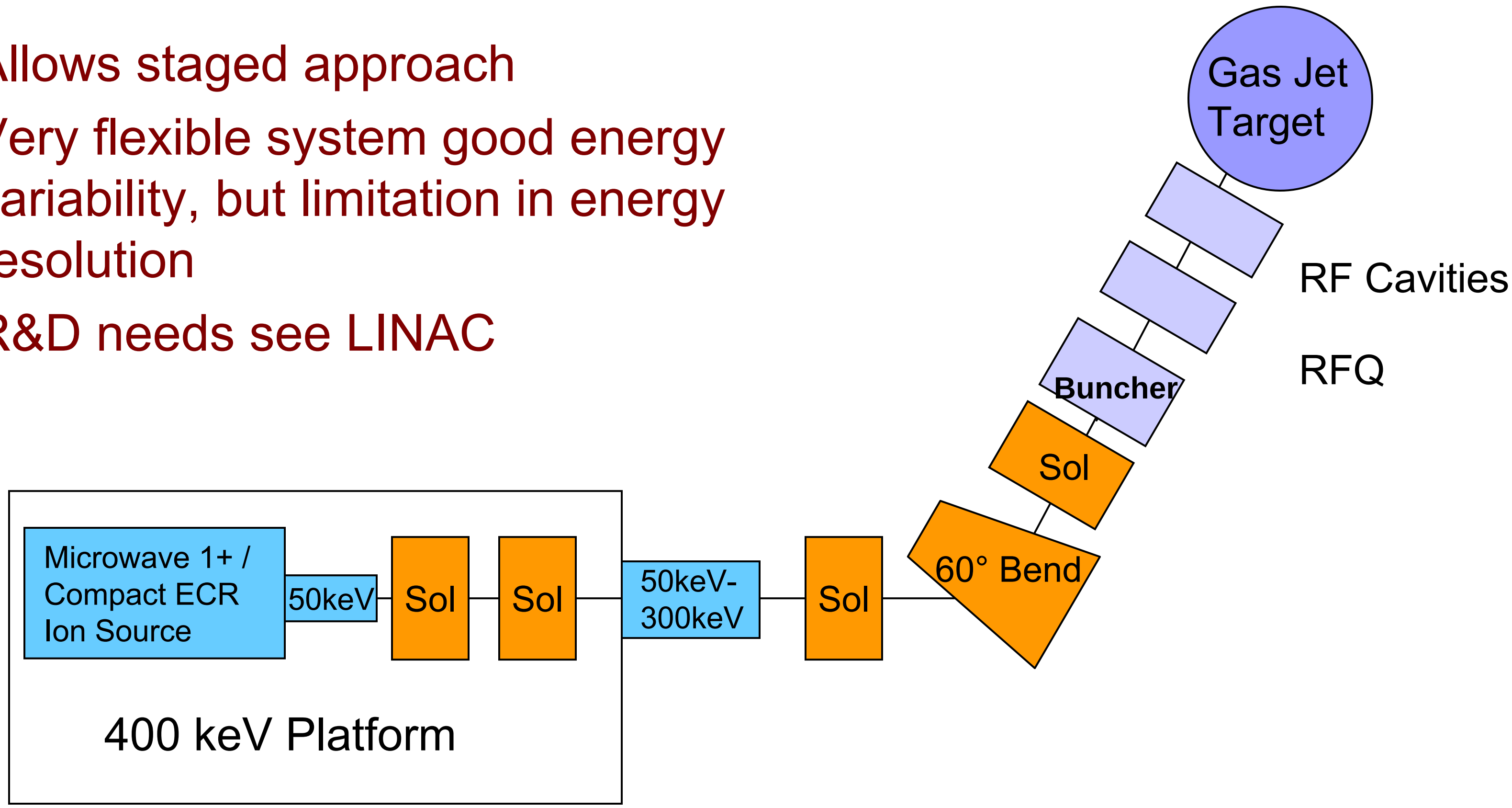


CLAIRE Low Energy Beamline



CLAIRE would be ideal injector into and RFQ/LINAC accelerator

- Allows staged approach
- Very flexible system good energy variability, but limitation in energy resolution
- R&D needs see LINAC



Summary

- Several attractive accelerator options and many trade offs
- Need clear input of priorities before a design decision can be made
- CLAIRE would be a powerful, complementary low energy machine or/and a flexible RFQ injector
- Design/R&D study 3-4 people, 1 year should be conducted to arrive to an optimized design solution

R&D items

Design decision

- **Energy range, intensities, system flexibility**

DC Accelerator

- **High intensity ESQ DC accelerator or traditional accelerator**
- **Compact ECR ion sources for medium charge states**

LINAC

- **Flexible low energy injector (CLAIRE)**
- **Study to optimize the design parameters for this application (CS, intensities, SC…)**
- **Optimize buncher to minimize the energy spread**
- **High resolution beam line vs high intensity beam line ?**

CLAIRE

- **Moveable high voltage gap**
- **Neutralization of beam through the analyzing magnet for high intensity beams**
- **Gas jet target/ ion beam interaction**